AVALANCHE HAZARD REDUCTION USING THE AVALANCHE GUARD: A CACHE AND MORTAR TECHNOLOGY

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ABSTRACT: The Wyoming Department of Transportation (WYDOT) in Jackson, Wyoming installed and successfully operated the Avalanche Guard, an automated, remotely operable, fixed cache and mortar delivery system for avalanche control. The Avalanche Guard is installed on Teton Pass, Wyoming, and was operational during the 2003/04-winter season. This operational trial of the Avalanche Guard was the first successful attempt in North America (excluding Alaska) to install, cache live explosives, and operate remotely, via PC and RF Telemetry, with permitting from the Bureau of Alcohol, Tobacco, and Firearms (BATF), and the USDA Forest Service (USFS). Two stationary Avalanche Guards were installed on two separate avalanche paths, each with the capability of caching and delivering 20, 3.0 Kg charges, as well as, providing starting zone coverage of 300 meters. The objective was to demonstrate and evaluate a system that can improve all weather explosive delivery efficiency and cost effectiveness for State DOT avalanche control programs on the winter and alpine roads of the western United States. Experiences from the permitting, installation, and results from winter 2003/04 are presented.

Keywords: avalanche control, avalanche hazard reduction, artificial avalanche release, transportation

1. INTRODUCTION

Increased travel demand on the winter/alpine roads of the Western USA has resulted in a dramatic increase in the hazard to motorist and maintenance section personnel from snow avalanches. These encounters are often disastrous.

Presently, the state of practice for managing avalanche hazards on the winter and alpine roads of the western United States is avalanche hazard forecasting, coupled with active control measures (explosive initiation of the avalanches) while the road is temporarily closed. Operations of this style are carried out on roadways in Alaska, California, Colorado, Idaho, Montana, Nevada, Utah, Washington, and Wyoming, as well as in Canada and Europe. However, growth in overall risk to motorists and maintenance section personnel is out-pacing our ability to adapt this present method of operation to meet safety objectives.

Typically, the scale of the problem is largest in States with mountains and people; California and Washington. By virtue of pure spatial scale alone, Alaska also has a significant and expensive avalanche problem on roadways. Colorado and Utah's problems are of similar scale. Idaho, Montana, Nevada, and Wyoming each maintain modest State programs in avalanche hazard management.

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In western Wyoming, as a consequence of the rapid urbanization of the greater Jackson, WY area, the hazard to motorists and Wyoming Department of Transportation (WYDOT) highway maintenance personnel from avalanche activity in Teton Pass on US Route (USR) 22 has increased. In addition to being the primary regional trunk road into and out of Jackson, Wyoming from Idaho and points west, USR 22 is the principal route for east-west commuter traffic and commercial traffic in western Wyoming. Similarly, USR 189 which passes through Hoback Canyon, south of the Jackson area is heavily used both by commuter and commercial traffic into and out of the Jackson area (Figure 1) to points north and east in the Big Horn basin and points south, including access to I-80.

State DOT avalanche hazard management programs, including WYDOT's on Teton Pass and Hoback Canyon are challenged by the need to deliver avalanche initiating explosive charges into the snowpack of avalanche starting zones, often well above the highway. These explosive delivery systems include military weapons, compressed air launchers, helicopter bombing, fixed gas/air exploders, and charges delivered by over-the-snow ground crews. Each of these explosive delivery systems has distinct advantages and disadvantages. The outlook for ammunition supplies for the military weapons is not assured. Compressed air launchers have limited range and limited low visibility operating limits. Their cost-per-shot is relatively high. Helicopter delivery of explosives is not an all-weather activity. More often than not, it is not possible to use helicopters at the precise time

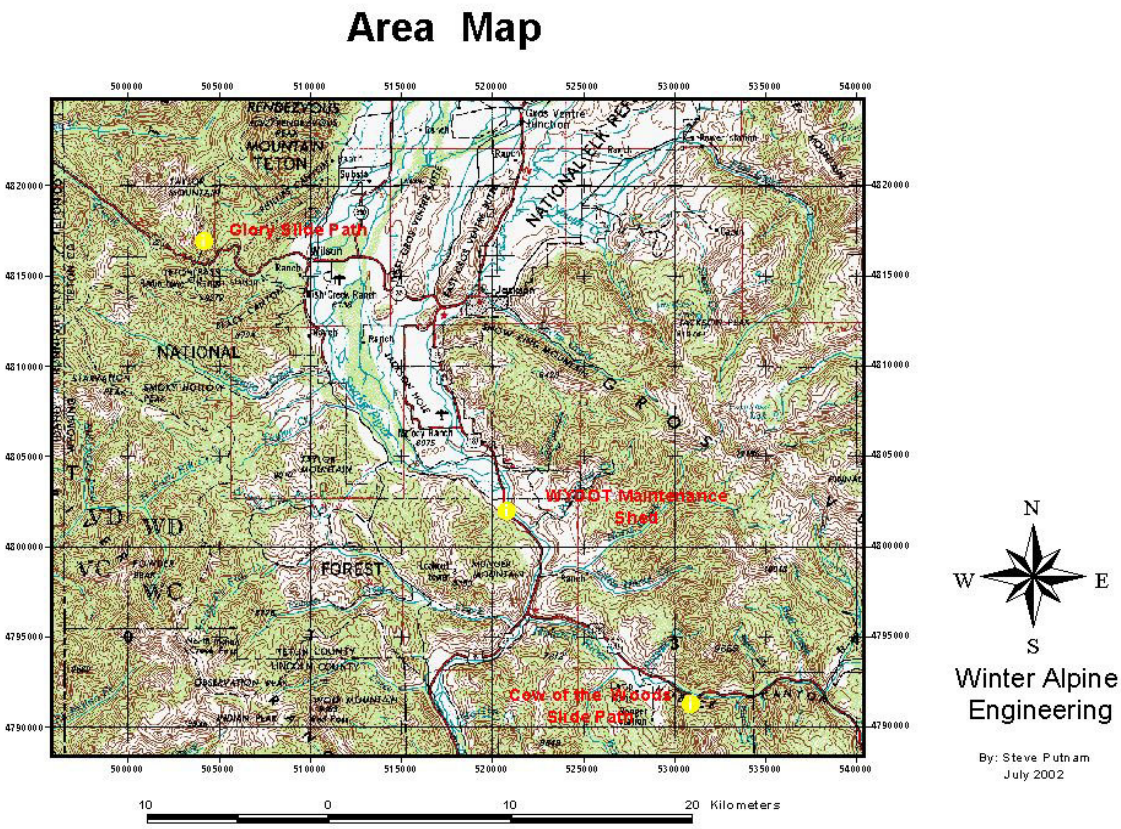


Figure 1. Jackson Hole area map showing the highway routes in and out of the Jackson, Wyoming.

when explosive initiation of avalanches is most probable and desirable. Fix gas exploders can be operated in all-weather situations. However, their explosive "foot-print" is limited to an area immediately adjacent to the exploder and hence every potential explosive shot point needs its own exploder. Manual delivery of explosives charges is precluded by both the distances above the highway that are involved and the fact that during times when avalanche explosive control is needed, it is not sound advice to be traveling over-the-snow in the same terrain. In addition, other novel delivery devices are in operation or being investigated (*Gubler and Wyssen*, 2002).

The objective of this investigation was to demonstrate, evaluate, and operationally integrate the Avalanche Guard, an avalanche control delivery system that can improve all-weather explosive delivery, efficiency, and cost effectiveness for the Wyoming Department of Transportation (WYDOT) avalanche control program on Teton Pass in WY. In addition, the objective was to investigate if the Avalanche Guard was a reliable, robust, and operational viable alternative (or additional) method for delivering avalanche control explosives to avalanche starting zones in all-weather conditions for State DOT avalanche control programs on the winter alpine roads of the western U.S. During the 2003-2004 winter season, the Avalanche Guard was deployed operationally and evaluated in WYDOT District 3 on Teton Pass.

The specific tasks associated with this investigation included: i) site planning for both Teton Pass and Hoback Canyon, ii) Avalanche Guard installation, training test firing, and operational loading, and integration, and iii) evaluation of system performance and operational integration, as well as lessons learned.

2. HOW THE AVALANCHE GUARD WORKS

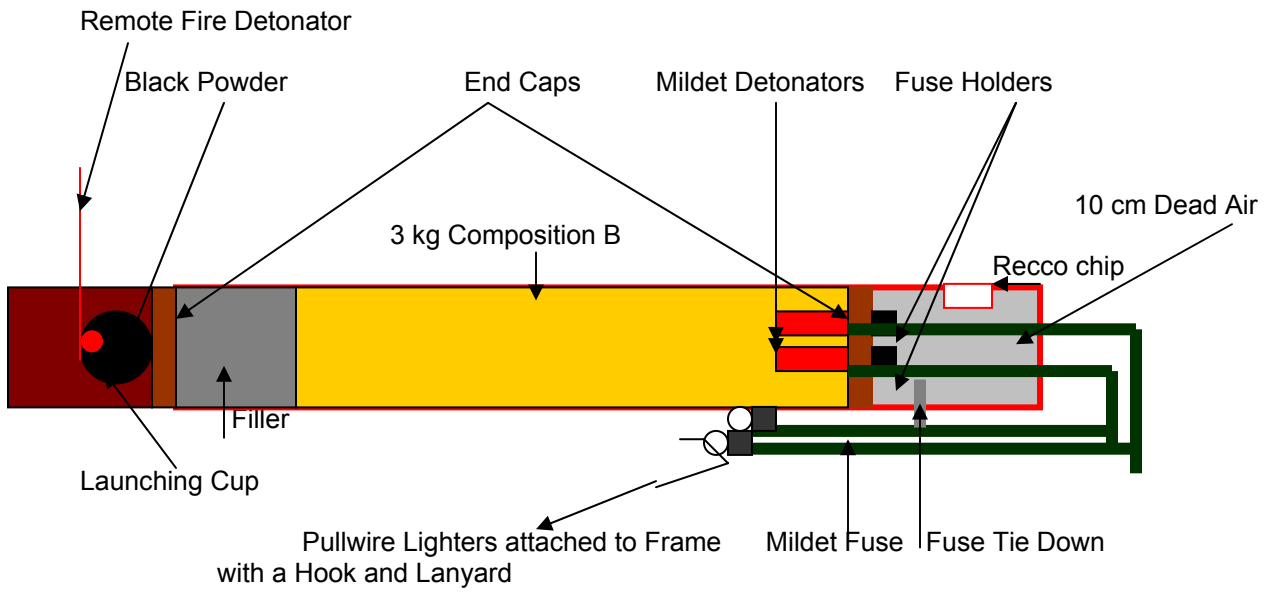
Prior to the operational avalanche season the magazine(s) are loaded with ten 3 kg charges with a black powder propellant capable of launching a charge 230 meters (Figure 2). The explosive charge is launched from the magazine via RF communication from a PC operated by authorized personnel. Instructions are received at the remote site and the specified explosive charge is launched. Upon launch a fuse is ignited by a mechanical ignition of the igniter as the charge is propelled out of the magazine. The explosive charge reaches its target and awaits the detonation of the blasting cap and hence the explosive charge. The charge delivered to the starting zone is a Composition B explosion, or Brissance, which describes the combination of a High velocity ($8{,}600\ \frac{m}{s}$) high gas volume and vacuum effect created from the explosion.

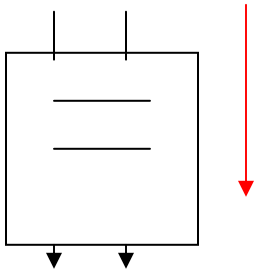
Advantages:

- Minimal personnel, set up and clean up on day of mission.
- Loading can occur on fair weather days, rather than during extreme conditions or in a hurry up situation.
- No air, electrical, or communications to remote units.
- Charge is relatively bio-degradable.
- Low cost per shot.
- Mission can be fired remote from site, insuring safety of personnel.
- Multiple targets from one site, in relation to direction and range.
- Unit is extremely weatherproof and rugged and meets BATF standards.
- Electronics and communications are based on industry standards.
- Consistency of shot placement.
- Unit can be relocated.
- Operation in adverse weather or darkness is possible.
- Small foundations => minimal footprint.
- No shrapnel.
- Adjustable if necessary after experience with installations.
- Only one mechanical moving part (door).

Disadvantages:

- Prior planning required for location.
- Foundation is immobile once placed.
- Range is limited to 230 meters.
- Use of explosives does require some expertise and training.
- Access to site required for reloading (or by long line on a helicopter).





Detonation Confirmation

For charges larger than 3 kg, reduce the filler space accordingly

Figure 2. Schematic of the Avalanche Guard Charge

3. INSTALLATION OF THE AVALANCHE GUARD

3.1 Site Selection

Glory Bowl and Twins avalanche path located on USR 22, Teton Pass, were selected for installation of the Avalanche Guard. Glory Bowl (Figure 3) is characterized by a return interval of 3 + avalanches per year, an open bowl with a channelized track, varying in elevation from 2,800 meters to 3,020 meters with an aspect of southeast to southwest, and a slope angle of 30-32 degrees. Estimated yearly snowfall is 1,000 centimeters. Traditionally, avalanche mitigation efforts deploy artillery, 3 Gaz Ex exploders, and heli-bombing.

Twins avalanche path (Figure 4) consists of two avalanche paths, Upper and Lower Twin. Upper Twin is characterized by a return interval of 4 per year, an open bowl with a channelized track, varying in elevation from 2,866 meters to 2,927 meters with a southern aspect, and a slope angle of 33-35 degrees. Estimated yearly snowfall is 1,000 centimeters. Traditionally, avalanche mitigation efforts deploy artillery, 1 Gaz Ex exploder, and heli-bombing. Lower Twin is characterized by a return interval of 4 per year, an open bowl with a channelized track, varying in elevation from 2,896 meters to 2,900 meters with an aspect of southeast to southwest, and a slope angle of 33-35 degrees. Estimated yearly snowfall is 1,000 centimeters. Traditionally, avalanche mitigation efforts deploy artillery, 1 Gaz Ex exploder, and heli-bombing.

3.2 *Permits for operation of the Avalanche Guard*

Permits to install and operate the Avalanche Guard are required from the Bureau of Alcohol, and Tobacco (BATF) and the USDA Forest Service (USFS). A variance is required from the BATF to store/cache unattended primed explosives. Variances are considered for approval on a case by case basis. However, the boxes which are constructed of 12mm steel and lined with 26mm 3-layer larch wood plates. The boxes are locked with two magnetic locking cylinders of 20mm in diameter. Further, the electric legwire connection panel located under the explosives compartment is locked with two padlocks having 20mm shackles. These boxes conform the Federal Explosive laws and regulations 200, Storage, Type 2 magazines, as well as, regulation 27 CFR Part 55 (Tour, 2000). In addition, the USFS requires an Environmental Impact Statement (EIS), however, due to the Gaz Ex installation on Teton Pass and the jurisdiction of the Federal Highway Administration (FHWA), an EIS was not required.

3.3 *Installation*

The Installation of the Avalanche Guard at Glory Bowl and Twins avalanche paths occurred in October 2003. The construction phase of the project included foundation, erection, and assembling of the units. Two systems were installed. Each unit/system (Figure 5 and 6) included two boxes on a single mast; each box is capable of storing and launching 10 individual rounds. The communication infrastructure, software installation, and test firing also occurred in October 2003.

4. RESULTS

The Avalanche Guard was successfully loaded and made operational on December 22, 2003, becoming the first fully operational system in the contiguous U.S. (*Sterbenz*, 2002). Forty charges were loaded and cached in the two installations (Glory Bowl and Twins avalanche paths) (Figure 7). During the 2003/2004 season, twenty-three rounds were fired and the geophones confirmed detonation for each round, thus resulting in no unexploded rounds.

The Avalanche Guard was deployed for five operational avalanche control missions.

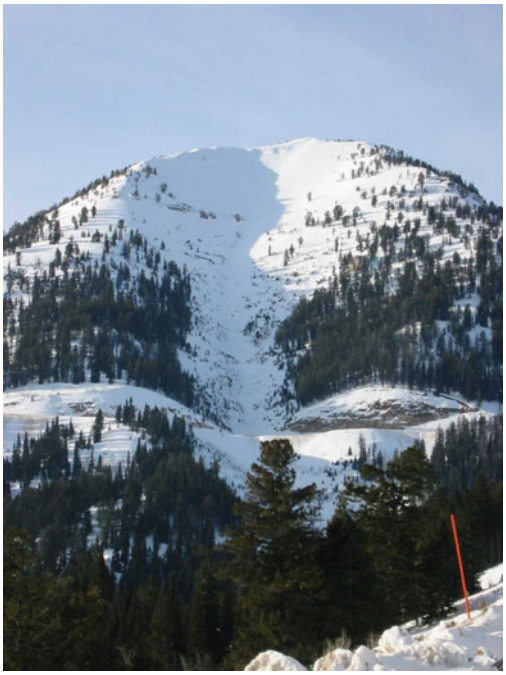


Figure 3. Glory Bowl avalanche path, USR 22, Teton Pass, Jackson, WY.

Figure 4. Twins avalanche path. Lower Twin is to the left and Upper Twin is on the right. USR 22, Teton Pass is in the foreground.

These five avalanche control missions were carried out without any technical difficulties (e.g. communications and mechanical). In addition, five missions were effectively carried out during the early morning hours prior to commuter and skier traffic over USR 22 (Teton Pass) and coordinated with the four Gaz Ex facilities in the Twin (1) and Glory Bowl (3) avalanche paths This operational regime demonstrated the effective coupling of existing control methods of WYDOT and the Avalanche Guard. The Avalanche Guard was never coordinated with the firing of the 105 Howitzer. The Avalanche Guard and 105 Howitzer provide similar coverage within the starting zone, therefore the deployment of the two control systems would not provide an effective use of resources. Coupling of the Gas Ex and the Avalanche Guard provides added coverage beyond the range of the Gaz Ex facilities. Further, the Avalanche Guard was successfully operated during all-weather conditions. For example, on March 6, 2004 the Avalanche Guard delivered five charges to the starting zones of Twin and Glory Bowl during the early morning when weather conditions were characterized by heavy snow and winds averaging $56\frac{km}{hr}$ and gusting to $121\frac{km}{hr}$. In addition, the Avalanche Guard produced an artificially released avalanche.

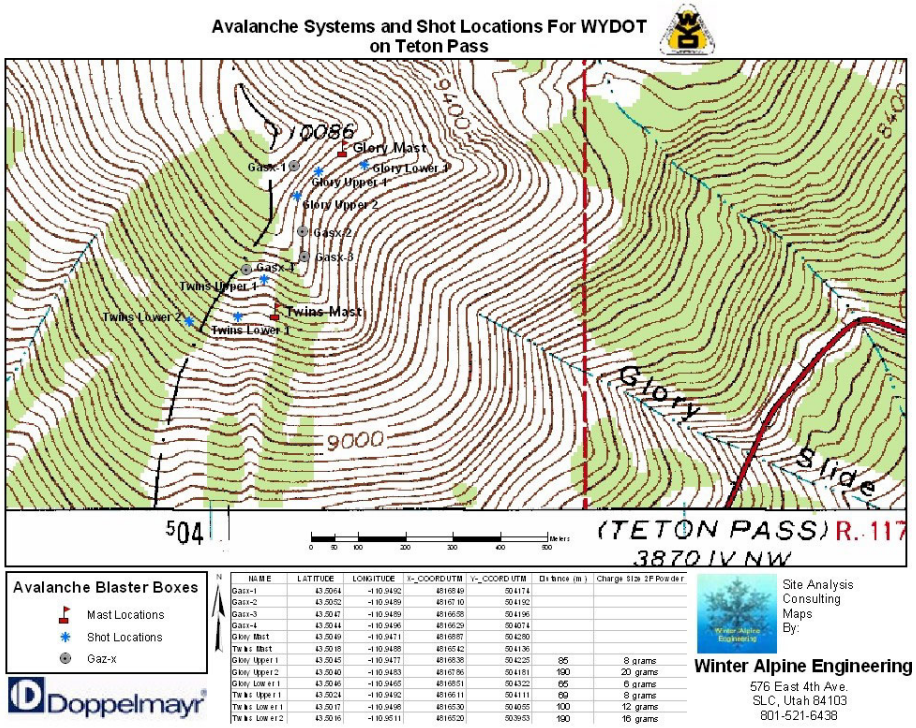
5. CONCLUSIONS

The objectives was to demonstrate, evaluate, and operationally integrate an avalanche control delivery to improve all-weather explosive delivery, efficiency, and cost effectiveness for the WYDOT avalanche control program on Teton Pass in Jackson Hole, WY. These objectives were met during the operational season of 2003/2004. However, the cost effectiveness of the Avalanche Guard is still under investigation and on-going.

The operation of the Avalanche Guard by WYDOT during operations demonstrates that an efficient avalanche control system can be implemented and integrated into the current operational program, increasing the timeliness of the operation without losing the effectiveness of the control mission. Operational evaluations indicated that control missions were short in duration and effective, producing numerous artificially released avalanches. However, the lengthy road closures resulted from other variables (i.e. severe weather along USR 22)

Figure 5. Avalanche Guard, Glory Bowl, October 2003.

Figure 6. Avalanche Guard, Twins Slide Path.



NAME	LATITUDE	LONGITUDE	X-_COORD UTM	Y-_COORD UTM	Distance (m)	Charge Size 2F Powder
Gasx-1	43.5064	-110.9492	4816849	504174		
Gasx-2	43.5052	-110.9489	4816710	504192		
Gasx-3	43.5047	-110.9489	4816658	504196		
Gasx-4	43.5044	-110.9496	4816629	504074		
Glory Mast	43.5049	-110.9471	4816887	504280		
Twins Mast	43.5018	-110.9488	4816542	504136		
Glory Upper 1	43.5045	-110.9477	4816838	504235	85	8 grams
Glory Upper 2	43.5040	-110.9483	4816786	504181	190	20 grams
Glory Lower 1	43.5046	-110.9465	4816851	504322	65	6 grams
Twins Upper 1	43.5024	-110.9492	4816611	504111	69	8 grams
Twins Lower 1	43.5017	-110.9498	4816530	504055	100	12 grams
Twins Lower 2	43.5016	-110.9511	4816520	503953	190	16 grams

Figure 7. Topographical map showing locations of the Avalanche Guard and Gaz Ex facilities in the Glory Bowl and Twins avalanche path, as well as the various shot placements for the Avalanche Guard.

and road clearing. The timeliness of the control mission is a direct result of the operational efficiency of the Avalanche Guard. For example, the 105 Howitzer during operation involves time consuming operational set up and protocols for operation. These operational procedures provide significant lag between road openings and closures, as well as man hours. However, the 105 Howitzer will still remain an effective and useful tool in avalanche control.

Preliminary studies indicate that the Avalanche Guard will provide a cost effective product for operational deployment of avalanche control. The cost per shot of $25.00 for the 105 Howitzer and $135.00 for the Avalanche Guard indicate that the Avalanche Guard is a costly option. However, in evaluating the cost effectiveness, the evaluation must include such important variables such as man-hours, highway closure times, and transportation of materials and supplies. Evaluation of the cost effectiveness is on-going by WYDOT personnel and will continue through the 2004/2005 operational season. However, early evaluation indicates that the Avalanche Guard decreases man-hours and the timeliness of road closures, thus providing a cost effective alternative to the operation of the 105 Howitzer.

Loading and unloading of the Avalanche Guard is a timely process that involves qualified and trained personnel. For example, at the end of the 2003/2004 season 23 rounds were expended and 17 rounds were unloaded from the four boxes in the Twins and Glory Bowl avalanche path, flown off the mountain, and stored in a magazine. All the cap and fuse assemblies for the unused charges were destroyed on site. During the unloading process it was extremely important to follow strict protocols in disarming and removing the charges. All the fuses most be cut prior to any other work, including the removal of the charges. This task and should only be performed by personnel with extensive experience with the Avalanche Guard system and explosive protocols. However, with experience, the loading and unloading processes will become

more efficient as personnel gain more knowledge of the system.

During the winter of 2003/2004 the Glory Bowl installation was buried in snow to the bottom of the boxes, burying the control box. Servicing became problematic with 2 hours of shoveling to uncover the control box. Of concern is the potential effect of snow creep damaging the control box. In addition, all the avalanche Guard rounds were not equipped with Recco reflector chips. Incorporating a Recco chip with the round would be beneficial to the locating and disposal of an unexploded round, especially with the large amounts of skier traffic on Teton Pass. Future charges will be equipped with a Recco chip.

In Lech, Austria, during the 2003/2004 winter season an Avalanche Guard deployment experienced a mass detonation, destroying a box with the cached explosives. The system failure resulted in a lanyard being hooked up in the door reinforcement and being pulled by opening the door for the next control mission, creating a mass detonation. This is the first "Swiss Style" unit built in Austria (There are over 120 units in Austria, but this was the first type as it is required in Switzerland). Further, the protocols for the firing sequence were different as those requested in Switzerland (in Austria, there is no requirement for firing in sequence yet) during this mission in Lech. Storage and launch boxes in North American market are built differently. The North American box has a 12mm wall and door thickness vs. 3mm in Europe and does not have the door reinforcement and impact protection that is required by the BATF. No one was hurt in the accident.

Overall, the Avalanche Guard worked well with excellent communications, software, and verification data. No operational problems were encountered with the system during the 2003/2004-winter season. The operation of the Avalanche Guard integrated well with WYDOT operations and provided a viable alternative for controlling avalanches along USR 22, Teton Pass. Further, the Avalanche Guard should provide a viable alternative and addition to avalanche control arsenal for State DOT's in the western U.S.

6. ACKNOWLEDGEMENTS

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